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DEMONSTRATION OF MANUFACTURING TECHNIQUES FOR APPLICATION OF HIGH PERFORMANCE CRYOGENIC INSULATION

D2-139267-1

Prepared by
Missile and Information Systems Division
THE BOEING COMPANY
Seattle, Washington

C. L. Lofgren - Program Manager
D. E. Gieseking - Technical Leader

Prepared for
National Aeronautic and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama

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FOREWORD

This report was prepared by The Boeing Company, Missile and Information Systems Division, under NASA Contract NAS8-21341. The work was administered by the George C. Marshall Space Flight Center, Manufacturing Engineering Laboratory, Marshall Space Flight Center; Alabama with Mr. I. C. Yates as Program Manager.

Contract NAS8-21341, "Demonstration of Manufacturing Techniques for Application of High Performance Cryogenic Insulation" was a nineteen week program (May 1968 to September 1968) consisting of demonstrating the insulation system developed on previous NASA Contract NAS8-21172.

Performance on this contract was under the direction of the Manufacturing Development Section, Missile and Information Systems Division of The Boeing Company. Mr. C.L. Lofgren was the Program Manager, D.F. Gieseking was Technical Leader and F. W. Dunn was the principal contributor.

LIST OF ILLUSTRATIONS

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1.0 INTRODUCTION

The insulation system demonstrated on this program was designed, analyzed, and a manufacturing plan developed on NASA Contract NAS8-21172 and reported in D2-109005-1. On that program a multilayer thermal protection system was designed for a 200-inch outside diameter toroidal liquid hydrogen tank. The multilayer system was required to have a thermal conductivity of 5×10^{-5} BTU-Ft./Ft.^{2}-hr.$^\circ$F or less, a density of 1.5 pounds per cubic foot and an arbitrary thickness of five inches was chosen as being representative of future requirements. Several of the insulation systems shown in Figures 1 and 2 met the program requirements. The design limit load factors for the system were 5.0G vertical downward, 1.5G vertical upward, and 0.5G lateral. A safety factor of 1.4 was applied to these to obtain design ultimate loads.

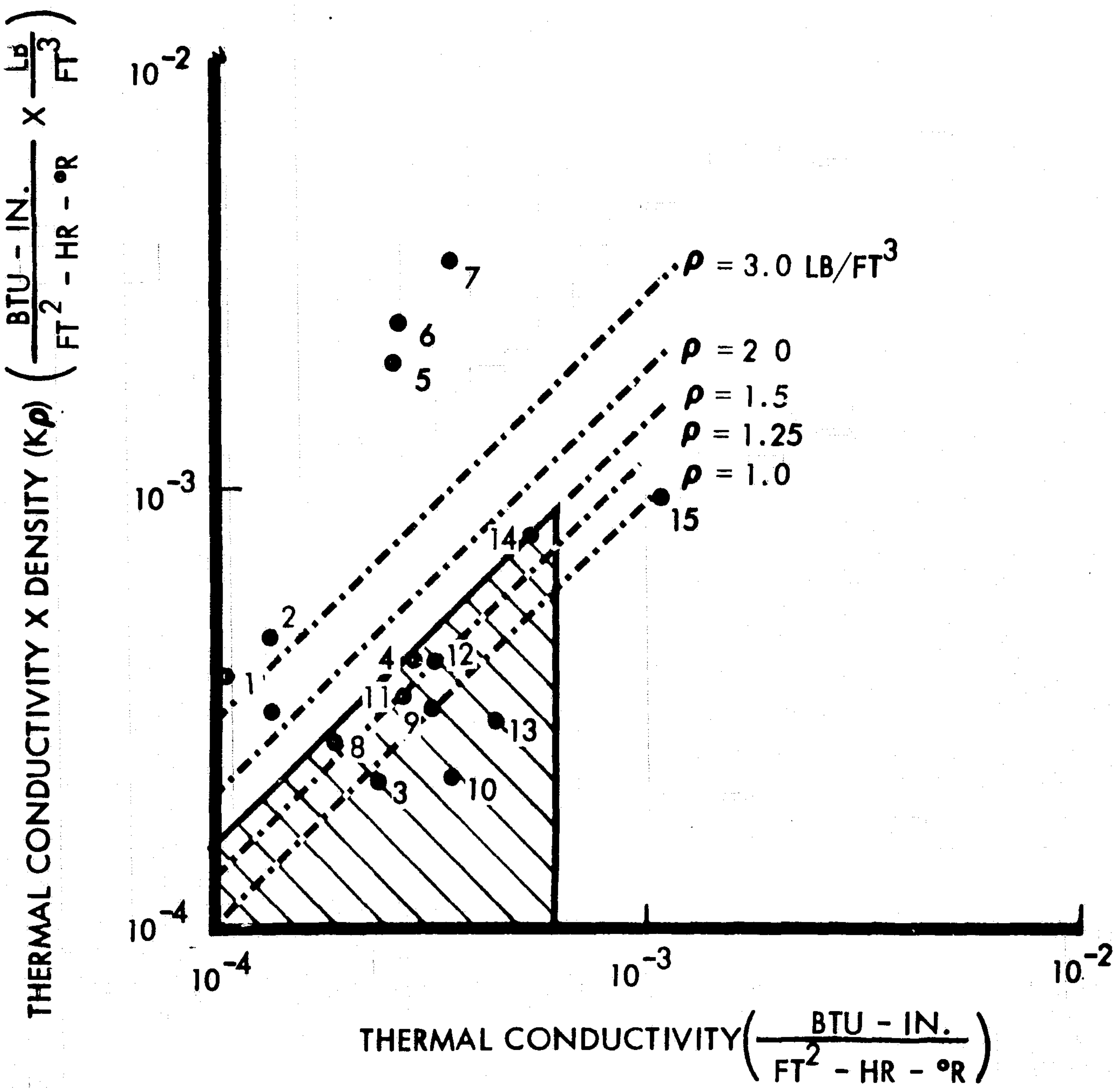
The heat leak summary of the designed systems is shown in Figure 3.

The insulation manufacturing plan, tooling development, and insulation application procedures were developed and documented in D2-109005-1, "Development of Manufacturing Techniques for Application of High Performance Cryogenic Insulation".

This program was conducted to demonstrate, on a full-scale 45 degree segment of the 200-inch diameter cryogenic tank, the fabricability and reproducibility of the insulation system designed on the previous contract. The investigation was composed of the following tasks:

- I - Mock-up Design and Fabrication
- II - Insulation System Fabrication
- III - Insulation System Demonstration

Following the demonstration, the mock-up was shipped to the Marshall Space Flight Center, Alabama where it was reassembled and demonstrated.



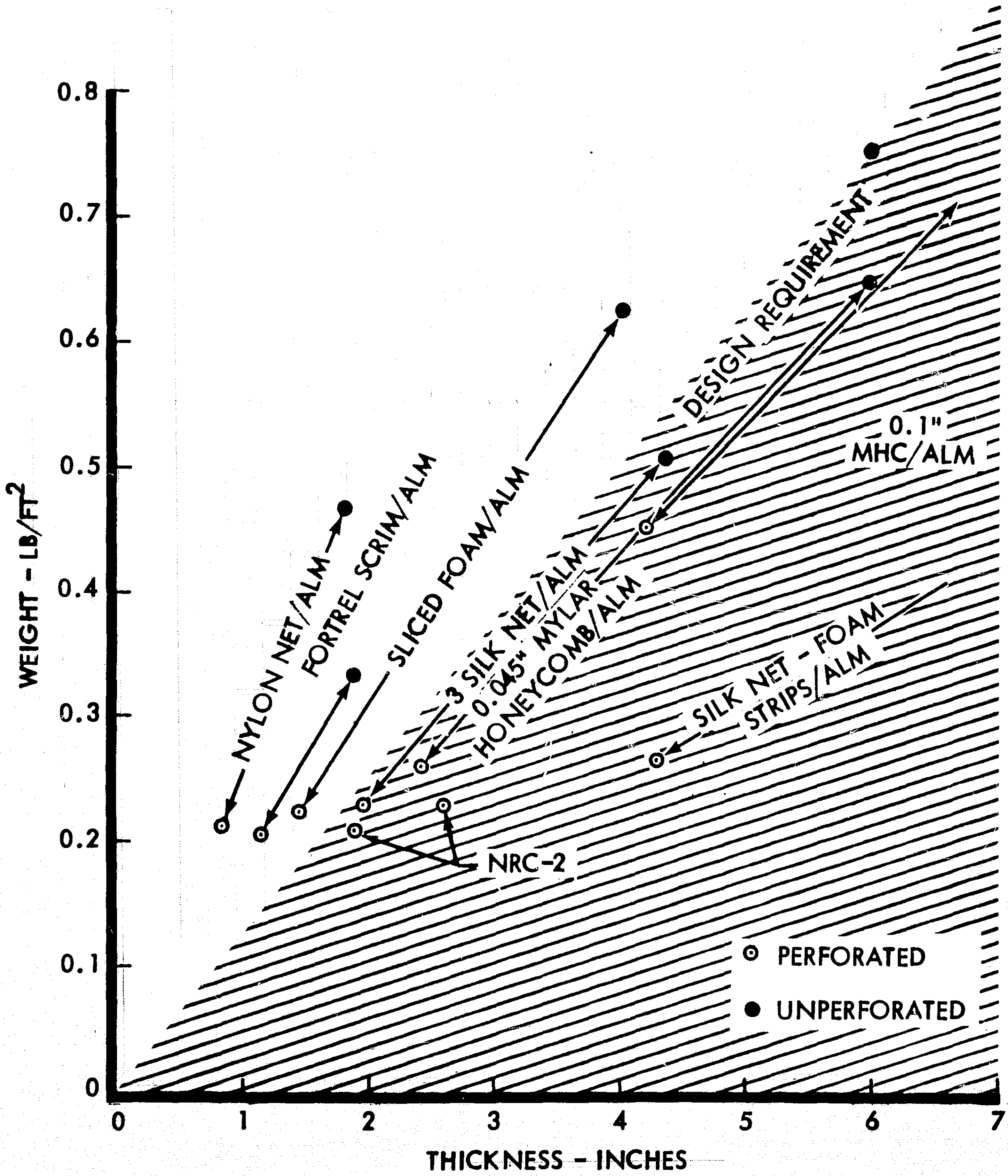
SHIELDS ARE ALUMINIZED MYLAR UNLESS OTHERWISE NOTED

HOT FACE . = 70°F
COLD FACE TEMP. = -320°F

1. Nylon Net
2. 2 Nylon Net/Layer
3. Micro Fibers Web/Alum. Foil
4. Sliced 3/4" Cell Mylar Honeycomb
5. 3 Mil Dexiglass/Alum. Foil
6. 5 Mil Dexiglass/Alum. Foil
7. 10 Mil Dexiglass/Alum. Foil
8. Sliced Polyurethane Foam
9. Sliced Foam + Foam Grid
10. Silk Net + Foam Strips
11. 3 Silk Net/Layer
12. 2 Silk Net/Layer
13. NRC-2
14. Dimplar
15. Dimplar (Deep Set Dimples)
16. Fortrel Scrim

EFFECT OF DENSITY ON THERMAL CONDUCTIVITY

FIGURE 1



INSULATION PROPERTIES

FIGURE 2

HEAT LEAK SUMMARY

SPACER MAT'L	HEAT FLOW (BTU / HR) NYLON NET	MYLAR HONEYCOMB
ESTIMATED ACTUAL PERFORMANCE IN ZERO "G", NO PERFORATIONS	10.4	30.4
PERFORATIONS IN RADIATION SHIELD	6.0	22.0
STUDS	8.9	8.9
SUPPORT WEB	0.2	0.2
THREAD TIES	0.3	0.3
TANK SUPPORT	10.0	10.0
MANHOLE INSULATION	5.0	1.0
TOTALS	40.8	72.8

FIGURE 3

2.0 SUMMARY

This final report represents the detailed results of a 19-week fabrication and demonstration of high performance multilayer insulation application to a 45 degree segment mock-up of a 200-inch diameter Torus tank.

A mock-up of a 45 degree segment of a 200-inch diameter Torus tank was fabricated of wood and fiberglass. The purge system, constructed of blue nylon for photographic clarity, was fabricated, installed on the mock-up and demonstrated. The insulation system was composed of five blankets of insulation each one-inch thick composed of alternate layers of nylon tulle and aluminized mylar film encapsulated in nylon net. The insulation blanket segments were installed on the mock-up using the designated insulation support systems.

Photographs were taken of the mock-up, insulation system fabrication and insulation installation for a sequential record.

The unit was disassembled, packaged and shipped to the Marshall Space Flight Center, Alabama where it was reconstructed and demonstrated.

3.0 COMPONENT FABRICATION AND INSTALLATION

3.1 Mock-Up Assembly

The initial phase of the program was to design and fabricate a full scale mock-up of a 45 degree segment of an existing 200-inch Torus tank to the artist's sketch shown in Figure 4 and the NASA-MSFC drawing of the tank.

The mock-up was designed of plywood and fiberglass so that it could be easily parted into two segments for shipping. The mock-up shown in Figure 5 was fabricated with the sump fairing and the Y-ring fairing simulated in place and the support skirt affixed. The views of the mock-up are shown as completed in Figures 6 through 9.

The manhole on the mock-up is half of the actual unit to allow demonstration of the removable insulation in that area.

The contour of the mock-up was checked after construction, prior to painting and found to be within 0.25 inch of the dimensions of NASA drawings 15-A-X-1101, 15-A-X-1103, and 15-A-X-1110.

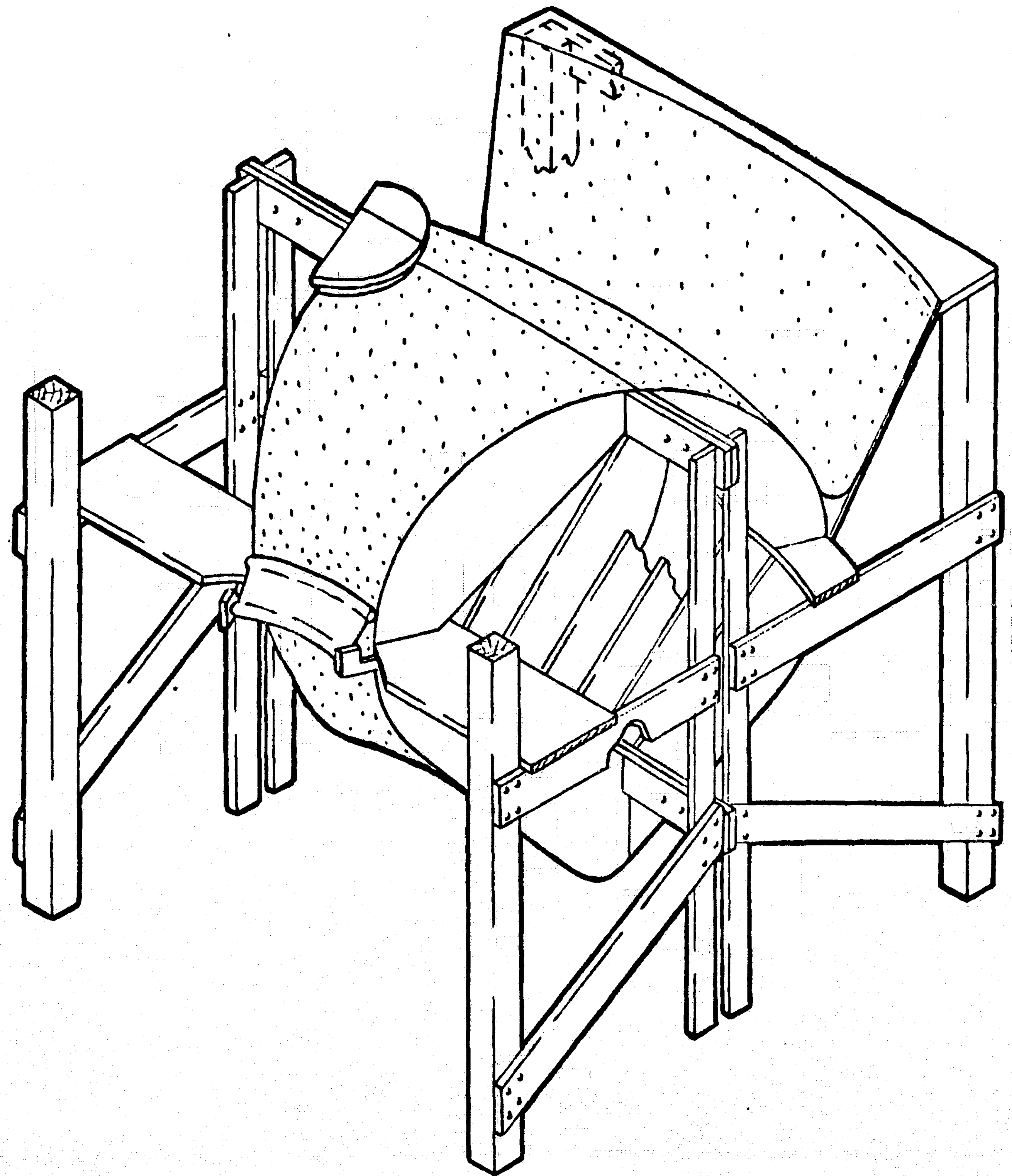


FIGURE 4

MOCK-UP SKETCH

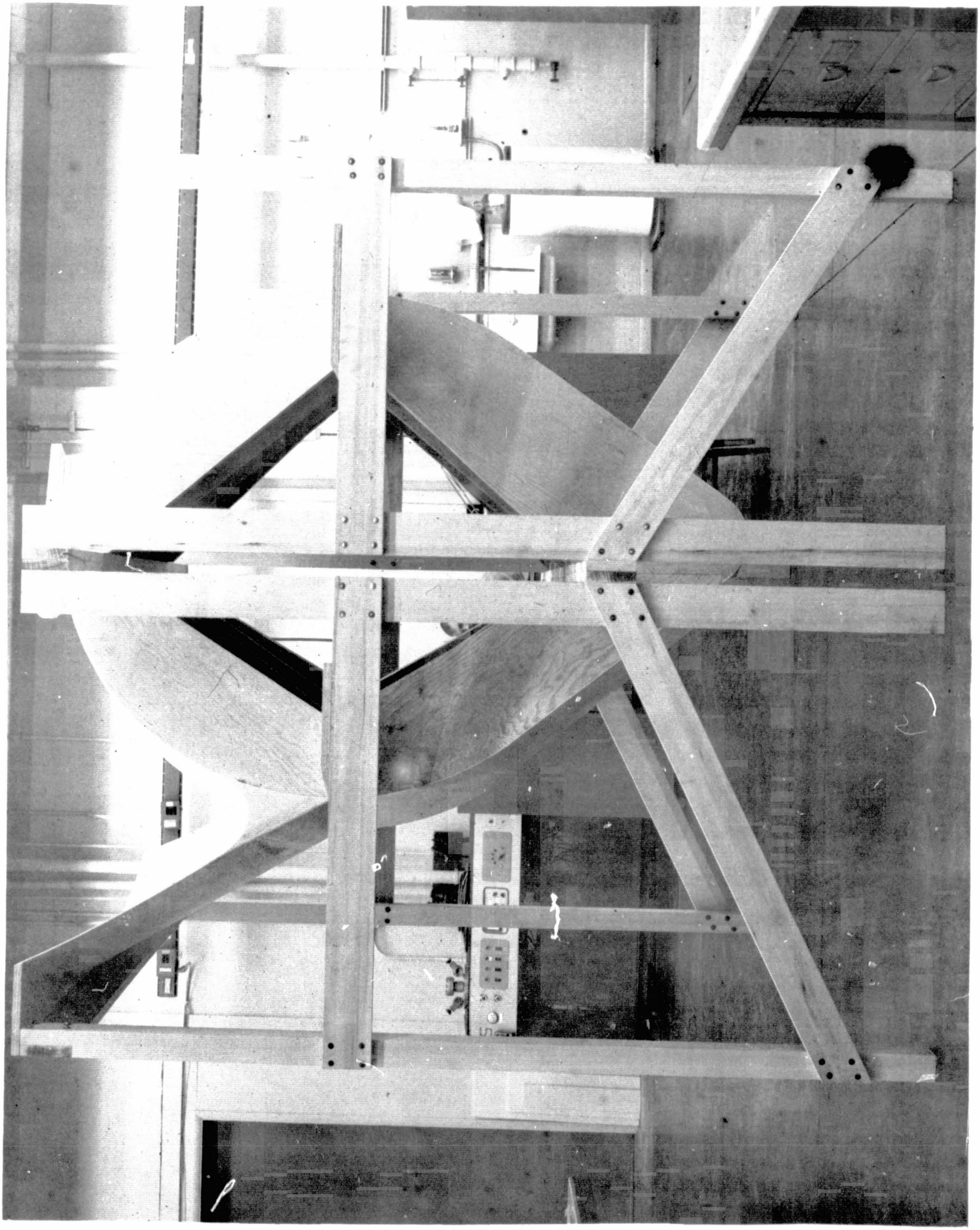


FIGURE 5

FULL SCALE 45-DEGREE SECTION TORUS TANK MOCK-UP - CROSS SECTION VIEW

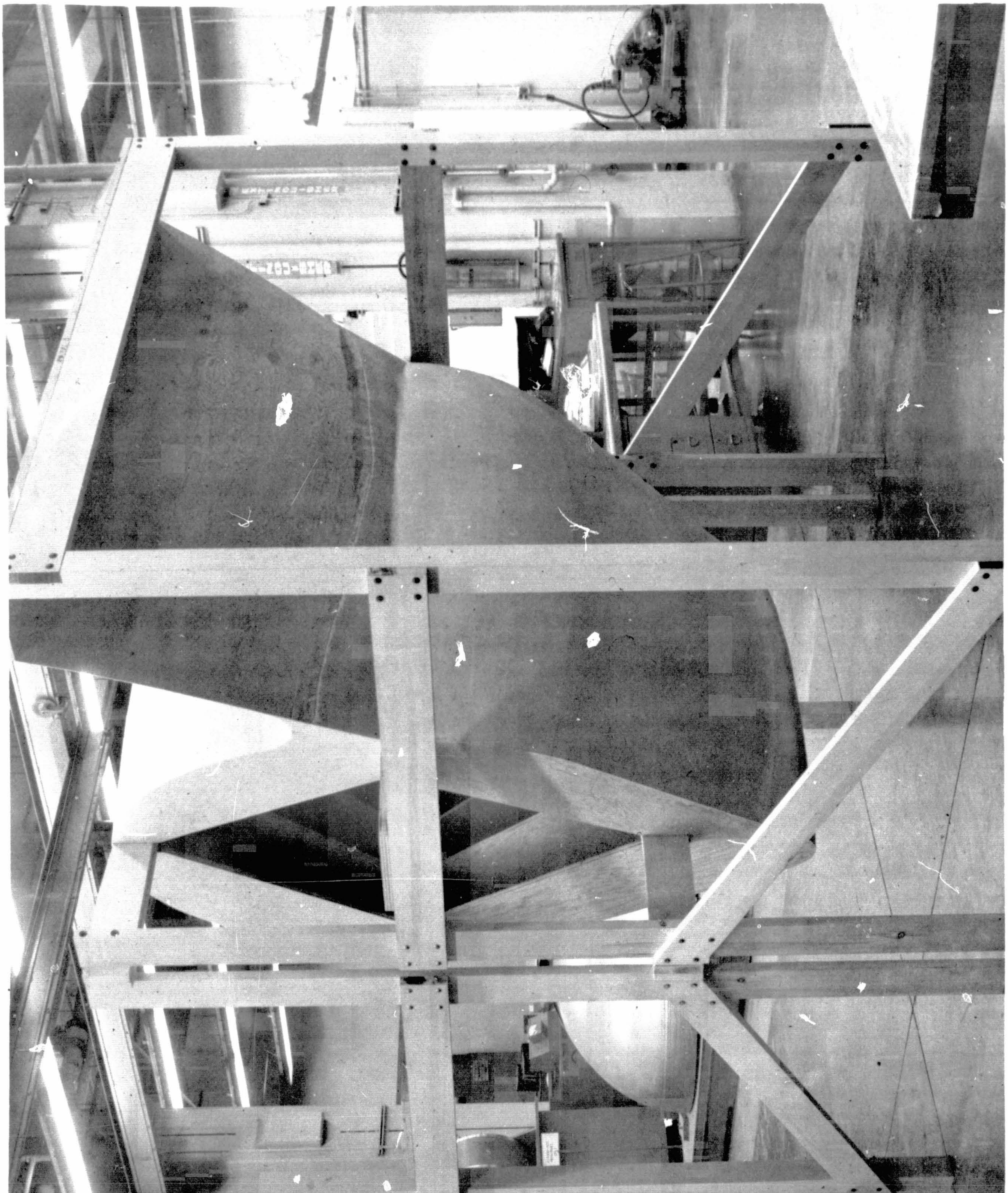


FIGURE 6

FULL SCALE 45-DEGREE SECTION TORUS TANK MOCK-UP

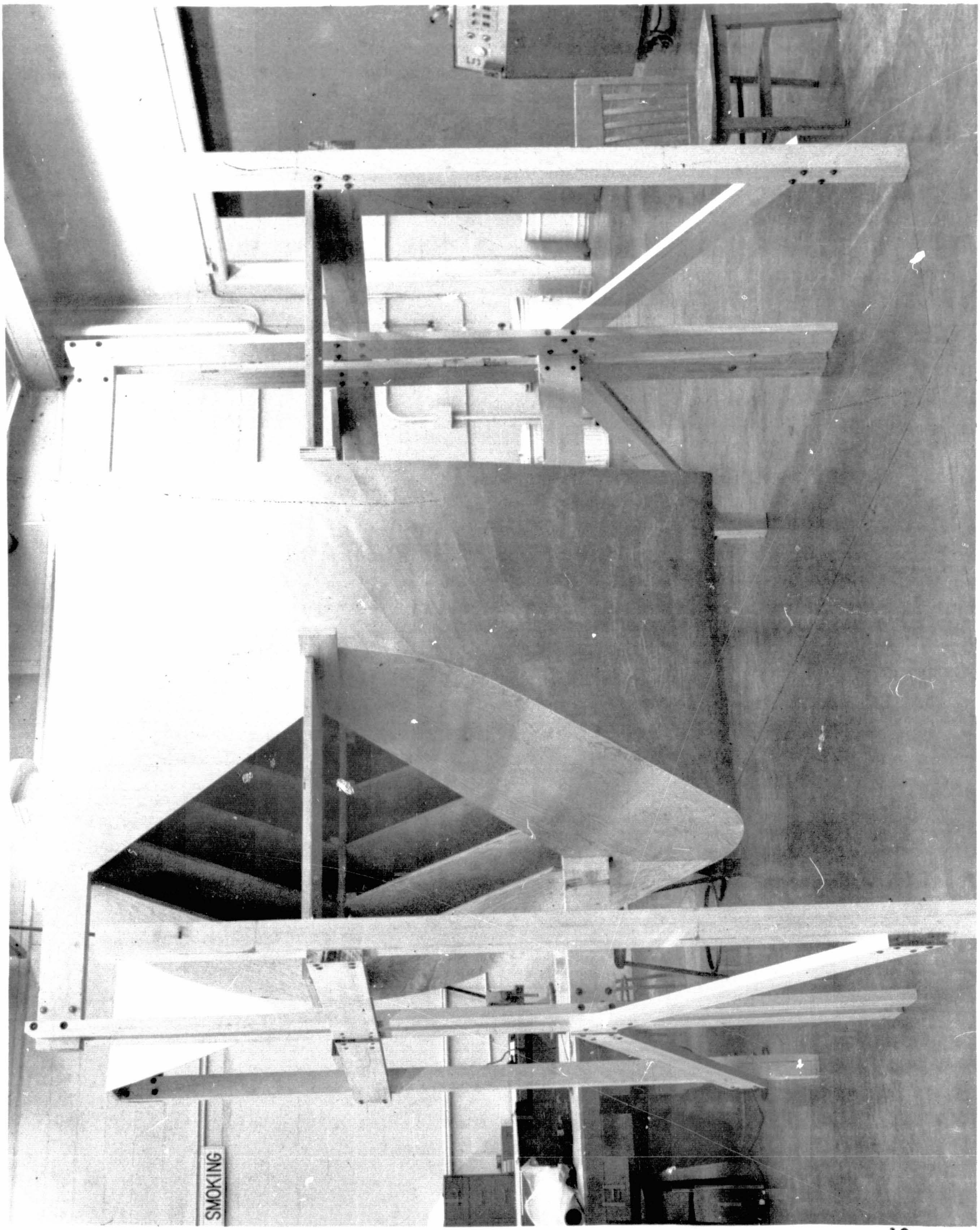


FIGURE 7

FULL SCALE 45-DEGREE SECTION TORUS TANK MOCK-UP

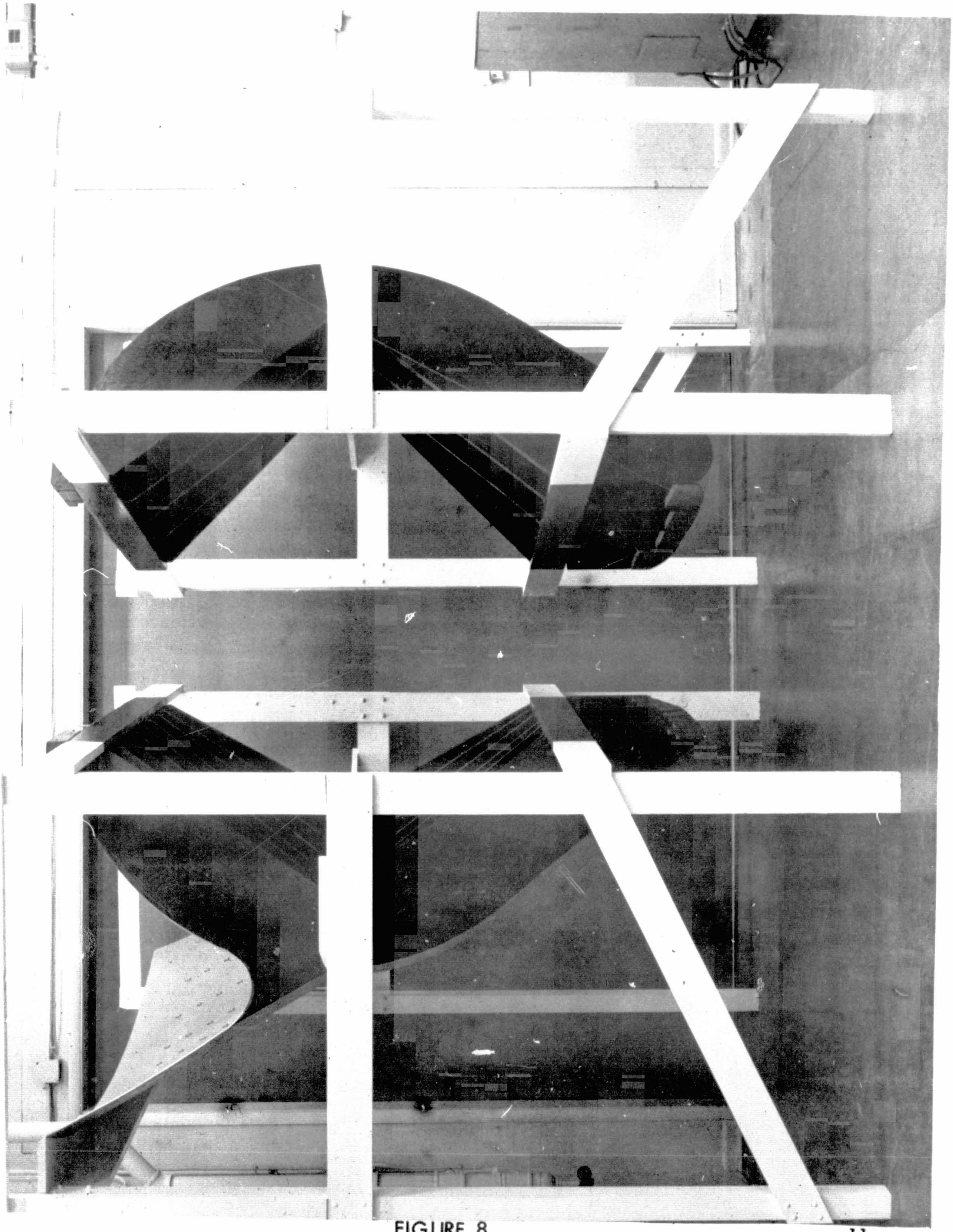


FIGURE 8

PAINTED MOCK-UP - SEPARATED CROSS VIEW SECTION

FIGURE 9
PAINTED MOCK-UP

3.2 Purge System

The purge system was fabricated per SK11-041071, sheet 5 of reference 1, except that blue nylon sheet material was substituted for the clear Mylar specified on the drawing to provide photographic clarity.

The three upper panels of the system, labeled and shown in Figure 10, were demonstrated. The top sheet of material was manually perforated and sandwiched with the underlying layer of film. Templates were used to cut the panels to size and were used as a guide for heat sealing into compartmented segments for more even gas distribution. The template also located all insulation support clip positions on the skirt. Cut-outs were made in the film at the locations marked and the areas were locally hand sealed with a hot iron. The films were heat sealed locally to effect double-walled compartmented segments. Using Mylar as the film for the panels, polyester adhesive film would be placed on the rim of the cut-out and heat sealed in place using a hot iron.

Nylon film feed tubes were fabricated and installed by manually fastening the tubes to nylon tees of 90 degree elbows which in turn were manually fastened to the perforated distribution tubes within the purge system segments. The purge system segments were tack bonded to the mock-up using contact adhesive. A distribution manifold system of metal tubing was fabricated to connect the distribution tubes to an outside source. This unit was necessary as the distribution tubes shown on the fabrication drawing crimped readily when they were bent to exit the insulation system. This difficulty was observed in all distribution tubes. Coarse weave fiberglass cloth was rolled into three layer thick tubes and inserted inside the distribution tubes. This prevented crimping of the tubes and did not noticeably reduce the gas flow through the tubes to the purge segments.

A demonstration of the purge systems was conducted but the efficiency of the system could not be determined either quantitatively or qualitatively. Positive gas pressure inside the purge system segments could not be maintained which indicated a discrepancy exists in the hole size and/or hole pattern in the system. Adequate purging would require an even gas flow passing through the perforations from inflated purge sections.

A redesign of the purge distribution system is indicated and desirable. The system shown in the fabrication drawing will not perform as required to adequately distribute gas to the purge segments. A metallic manifold positioned around and attached to the vent relief port for stability is recommended. Lateral distribution segments radiating to the adjacent manholes would distribute the gas to the transfer tubes for each purge section.

FIGURE 10

MOCK-UP WITH PURGE SYSTEM ATTACHED

3.3 Insulation Attachments

The insulation attachments for the system are specified on SK11-041071, sheet 1 of 5. Samples of each of the attachments are shown in Figure 11F except for the double-hoop assembly shown on the mock-up in Figure 12 and the insulation retainer which is shown separately in Figures 13 and 14. All attachments were fabricated to simulate the actual attachment in areas where cost of fabrication of the actual unit was prohibitive. In this category were the thread tie buttons, stud attachment discs and the radial insulation retainer stud. The insulation attachment clips were bolted to each side of the simulated support skirt as shown in Figure 15. It is recommended that the design be changed to invert the clips top to bottom to allow thread attachment in the hook portion. The double hoop support bracket was bolted to the mock-up. The double hoop support was fabricated of copper tubing and wrapped with nylon tulle. The upper tube was attached to the bracket shown in Figure 16. The lower tube was attached to arms bolted to the mock-up frame. Following the attachment bonding shown in Figures 17 and 18, the units were painted for photographic clarity.

Several problems were encountered in this section. The segmented stud shown on SK11-041071, sheet 1, detail V and in Figure 19 was difficult to position correctly to the depth specified on the retainer and to maintain alignment of the stud. Orientation was maintained by positioning a 0.25-inch diameter bolt through the center to the skirt attachment button. This bolt was removed and replaced after each layer segment was applied. The one-piece studs shown in SK11-041071, sheet 1, detail II offered difficulty in insulation blanket location, puncture of the blanket and fitting over the protruding member. The members are perpendicular to the surface of the sump fairing which is of a relatively short radius and does not allow placement of the perforated insulation over them without difficulty.

In an attempt to rectify the difficulties in manufacturing processing caused by the forementioned studs, a segmented stud was designed, fabricated and installed on the mock-up as a part of the insulation system demonstration. This stud, shown in Figure 11F, although a better thermal conductor, offered structural stability and fabrication and application simplicity not available in the other units. In the application of this stud, the segments were bonded to each other as the blanket insulation layers were installed on the cryogenic storage container. The stud performed adequately on the mock-up where it was installed on the tank to replace half of the segmented studs shown in Figure 20.

The insulation retainer shown in Figures 13 and 14 was fabricated per SK11-041071, sheet 1, detail I. Fabrication and installation of the retainer posed no difficulty, but the channel sections of the unit were not rigid enough to adequately conform to the tank-insulation configuration. It is recommended that the design of the channel be changed to give a channel dimension in detail I section A-A of 1-inch legs in addition to the present 1-inch width. The thickness of the unit part is adequate. This change will sufficiently stiffen this unit so that it functions properly in restraining the insulation.

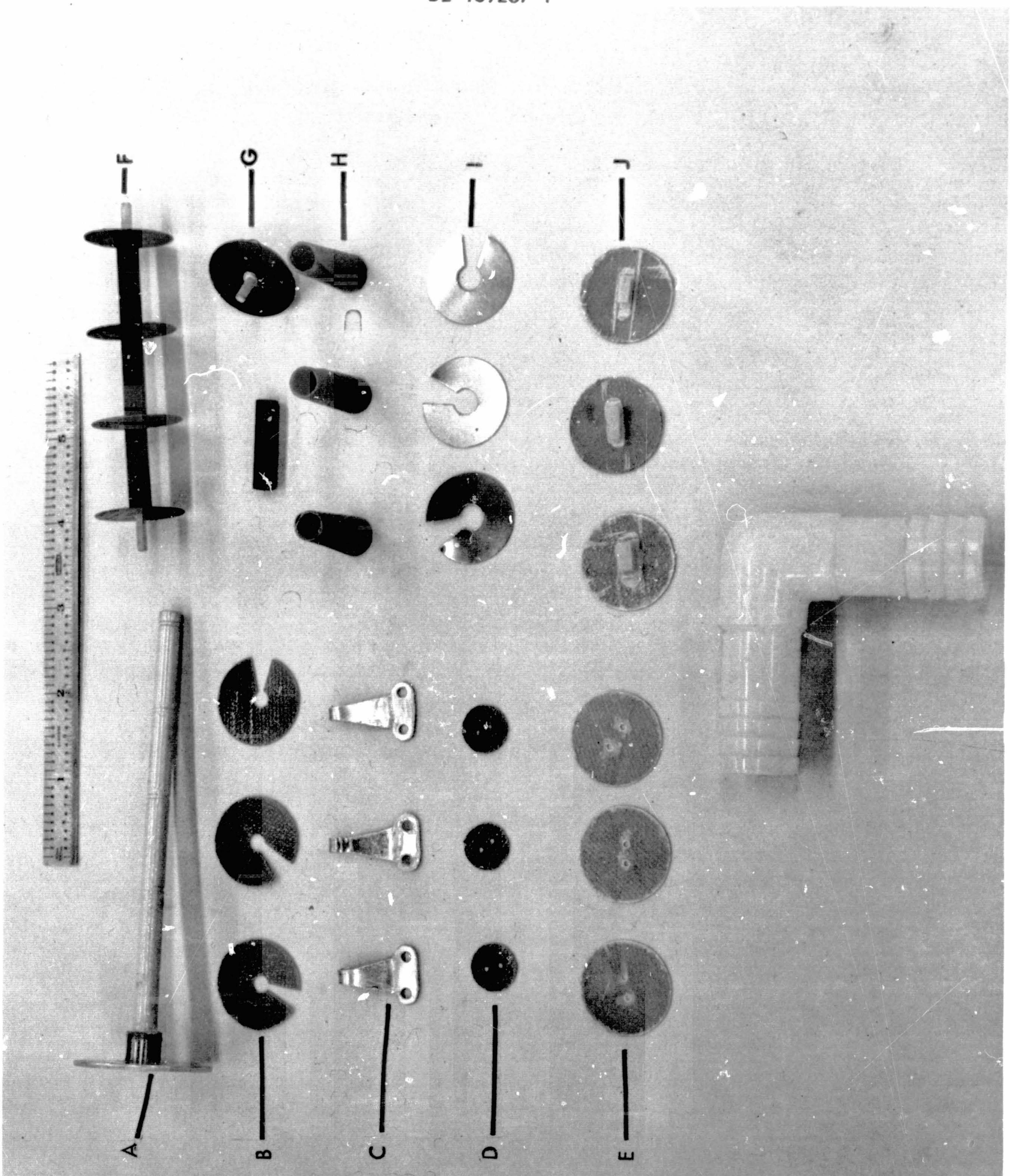


FIGURE 11

INSULATION HARDWARE COMPONENTS

FIGURE 12
DOUBLE HOOP AND SUPPORT WEB

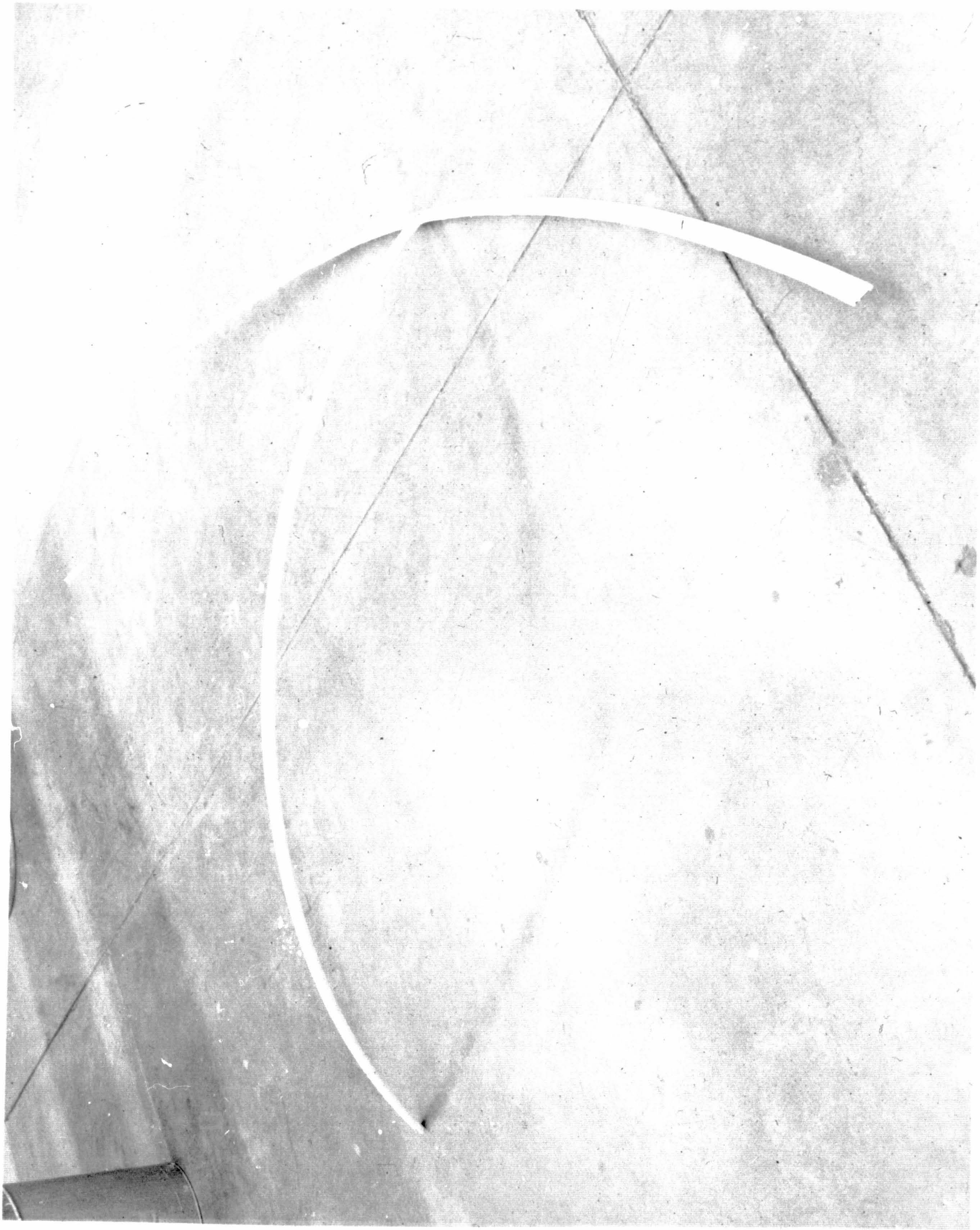


FIGURE 13

ASSEMBLED INSULATION RESTRAINER

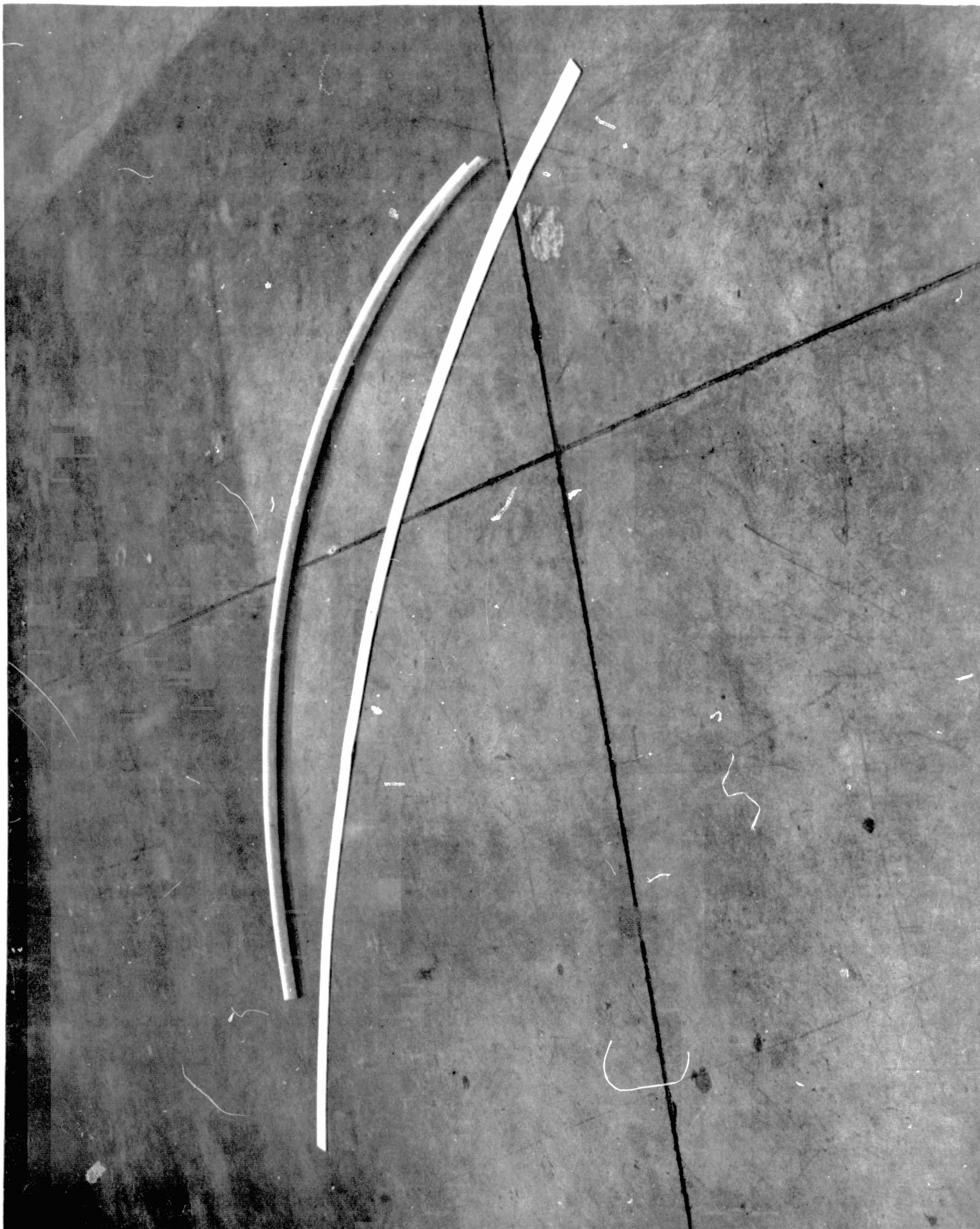


FIGURE 14

FIBERGLASS INSULATION RESTRAINER PRIOR TO ASSEMBLY

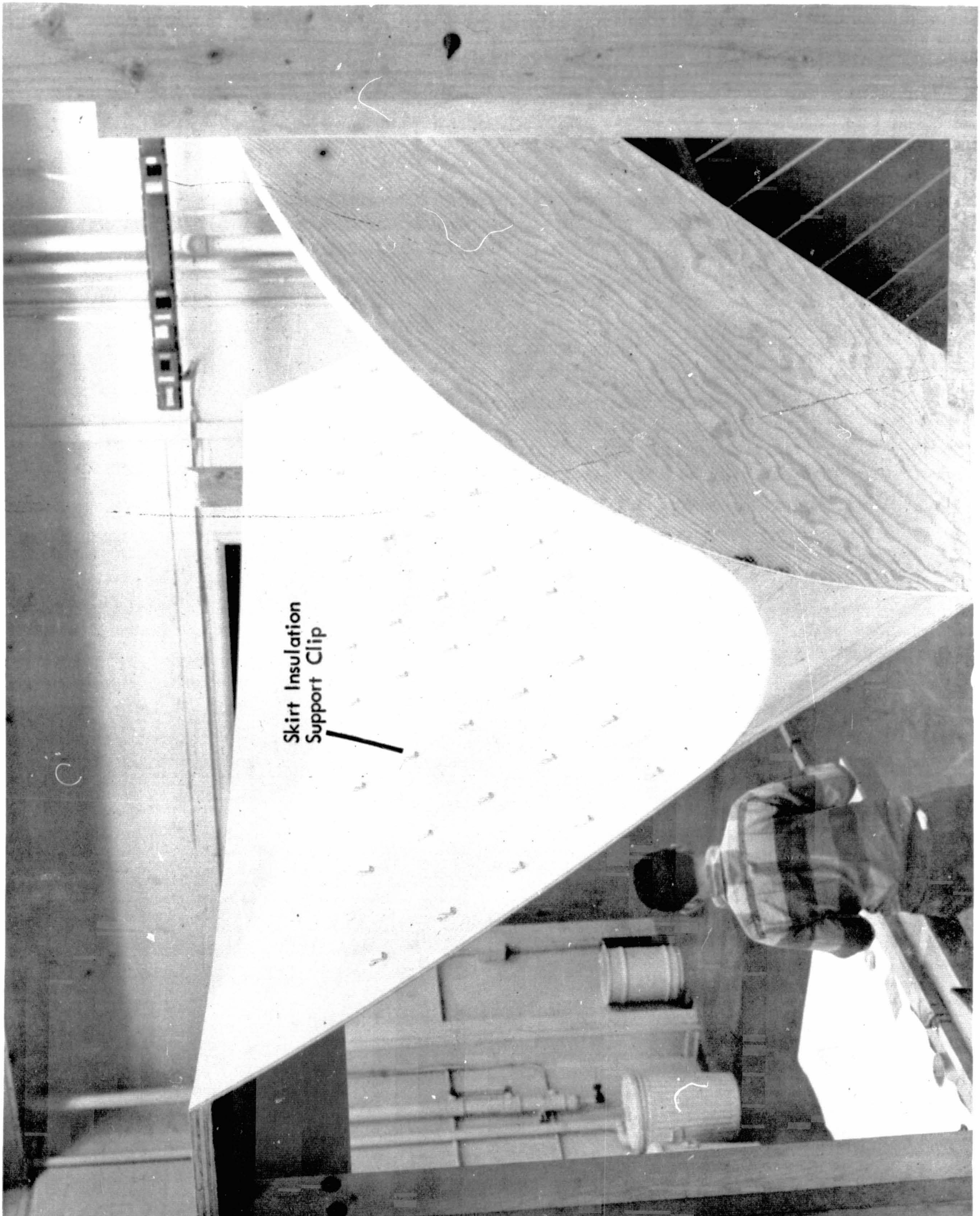


FIGURE 15

SUPPORT SKIRT WITH ATTACHMENTS

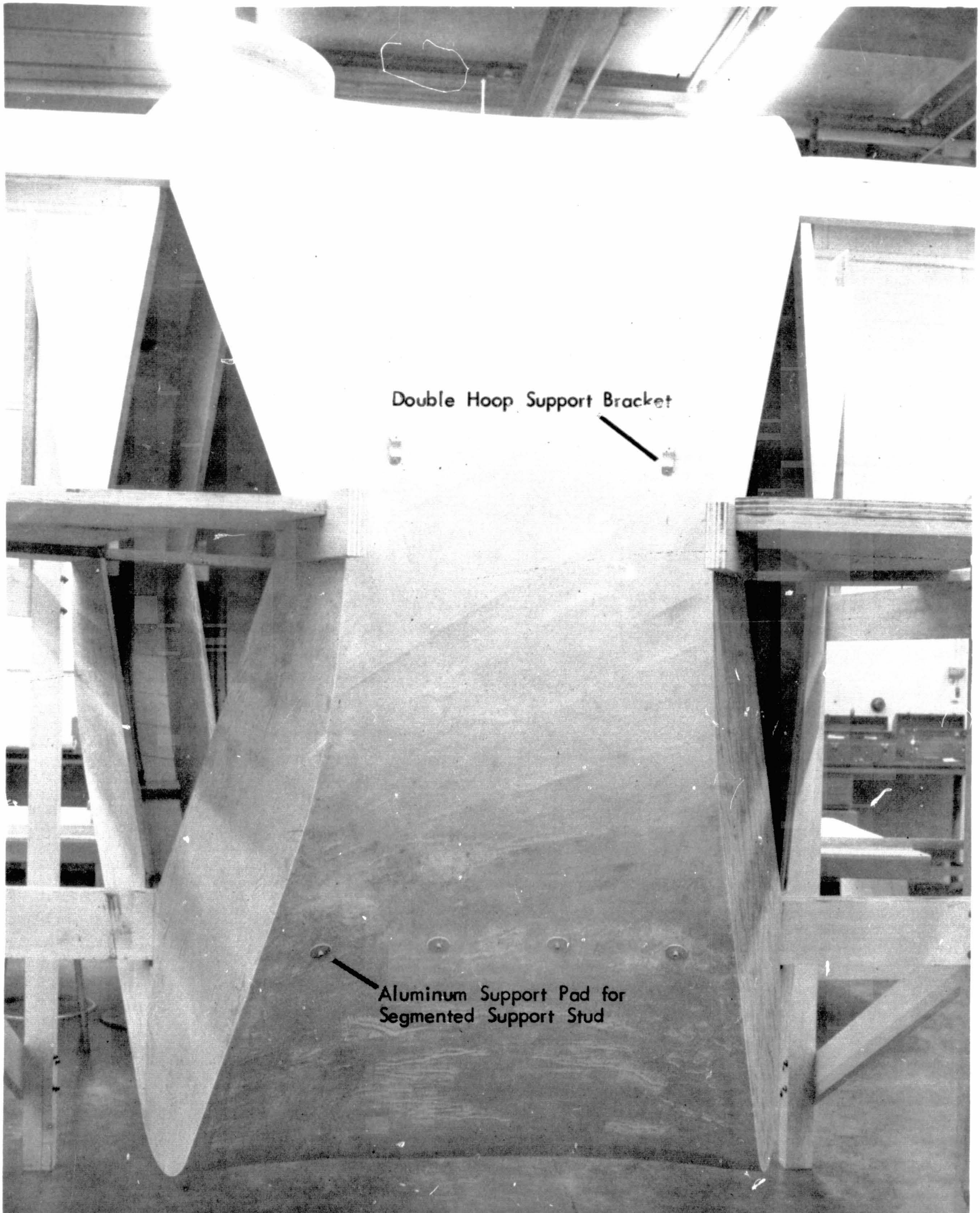


FIGURE 16

VIEW OF MOCK-UP

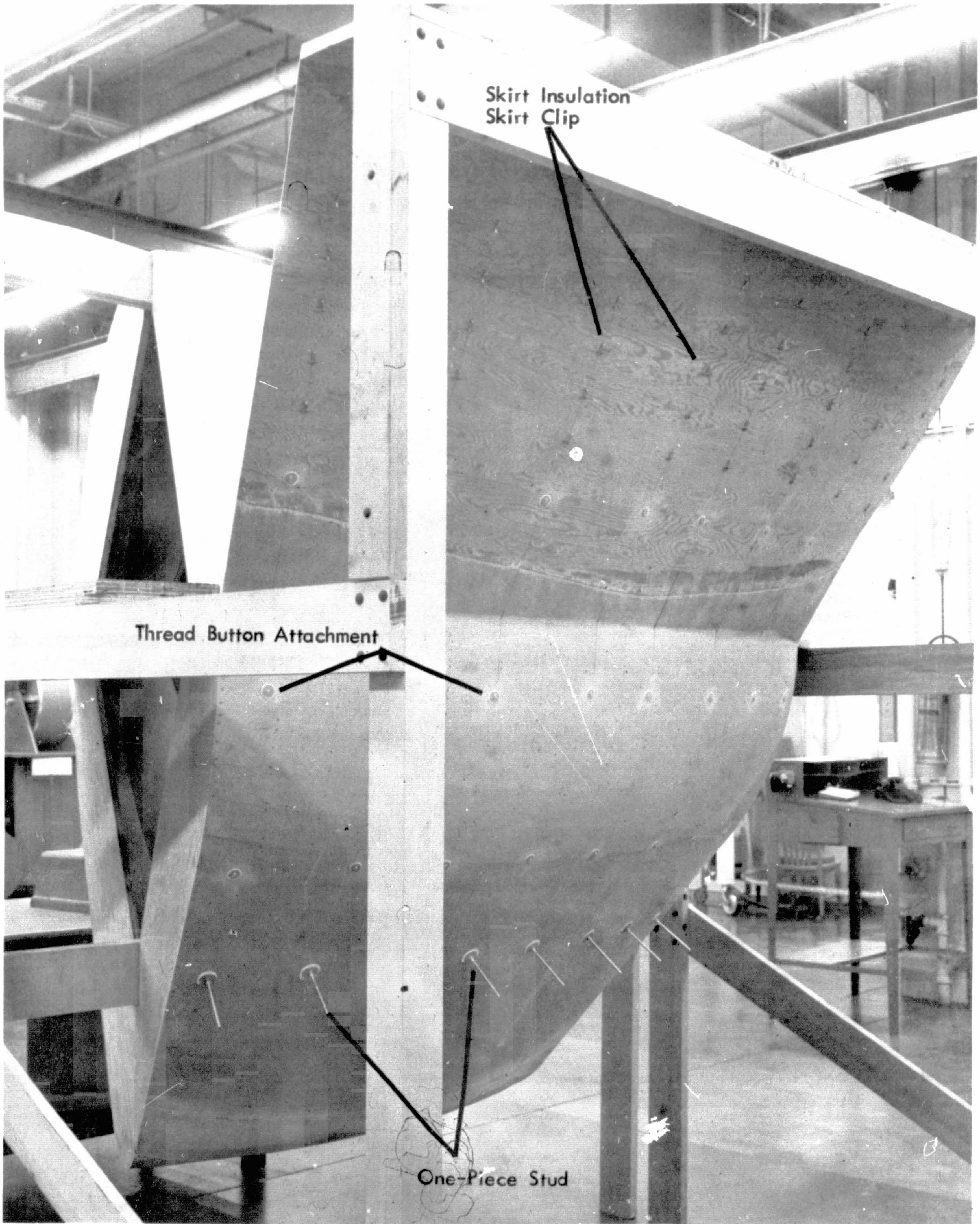


FIGURE 17
VIEW OF MOCK-UP

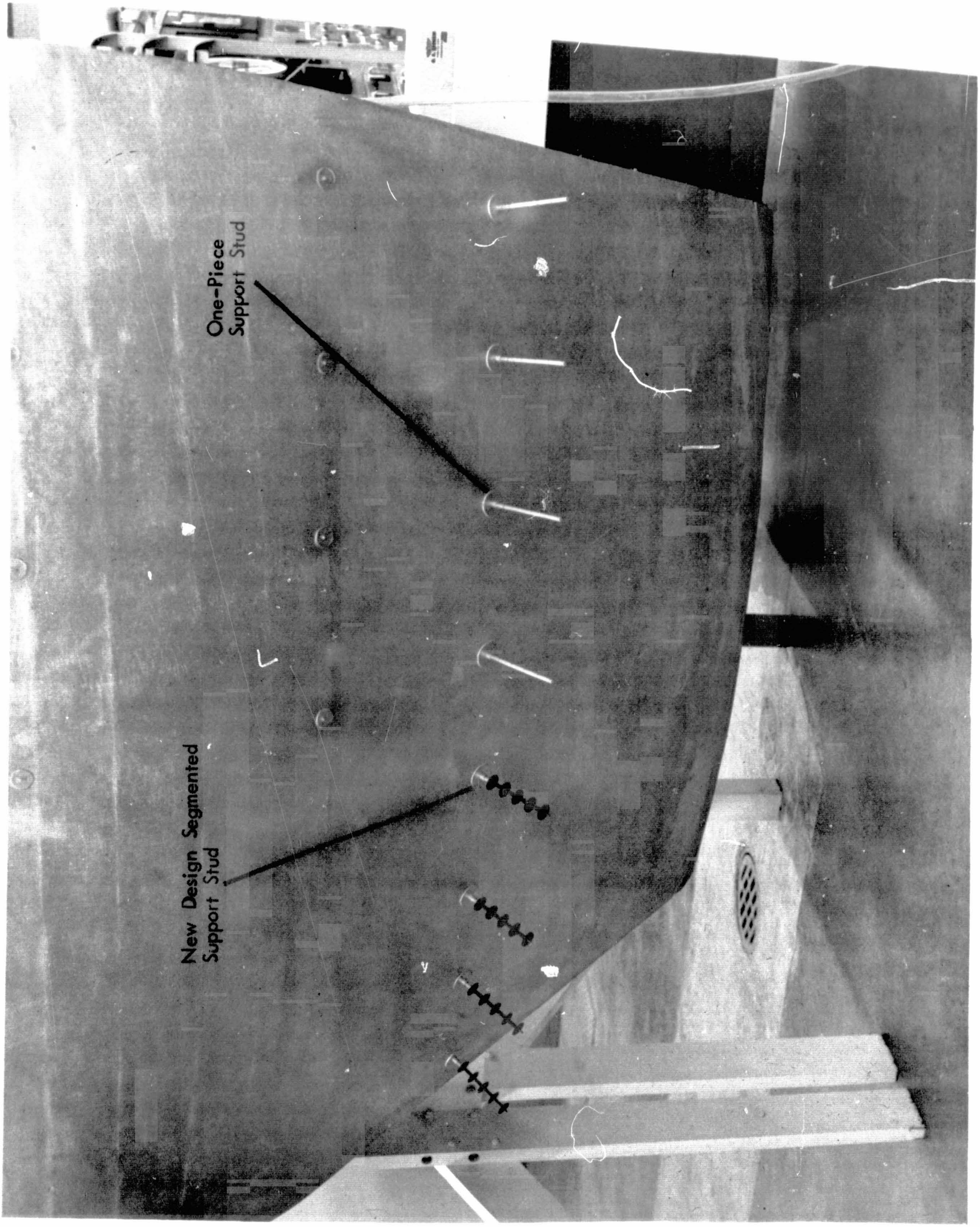


FIGURE 18

ONE-PIECE SUPPORT STUD AND SEGMENTED SUPPORT STUD

FIGURE 19
SECOND LAYER INSULATION POSITIONING TO SUPPORT WEB

FIGURE 20

DESIGNED SEGMENTED SUPPORT

3.4 Insulation Blanket Fabrication

Four insulation systems were considered for use on this program. Mylar honeycomb, Nomex honeycomb, sliced rigid foam, and nylon tulle separator materials with reflective shields of perforated aluminized mylar were evaluated. The latter separator was selected because the Nomex honeycomb and sliced foam were too expensive and the Mylar honeycomb was no longer available from the supplier.

The insulation blankets were fabricated by laminating the insulation system component layers on a cutting table as shown in Figures 21 and 22. A flat pattern template was fabricated to the tank geometry and the insulation materials were cut to size. The template marked the location of the thread and button insulation retainers used to maintain stability during handling and for cutting the blankets of insulation shown in Figure 23.

Both ends of the blankets were scarfed by cutting back one-half inch from the edge of the succeeding cut every fifth layer in the 55 layer composite to give a smooth taper joint. This was done using a template for uniform tapering of the blanket.

Nylon tulle, identical to the separators, was applied to the top and bottom faces. The facing material was sewn on the edges with nylon thread. Buttons were installed, using a template and thickness gauge, through the insulation blanket and tied. The knot was fused to prevent raveling of the thread. The installed buttons are shown in Figure 24. Reinforcement tape was sewn to each end of the blanket for attachment to the support.

The insulation blankets were stored in a protective wrap in a flat condition, totally unrestrained.

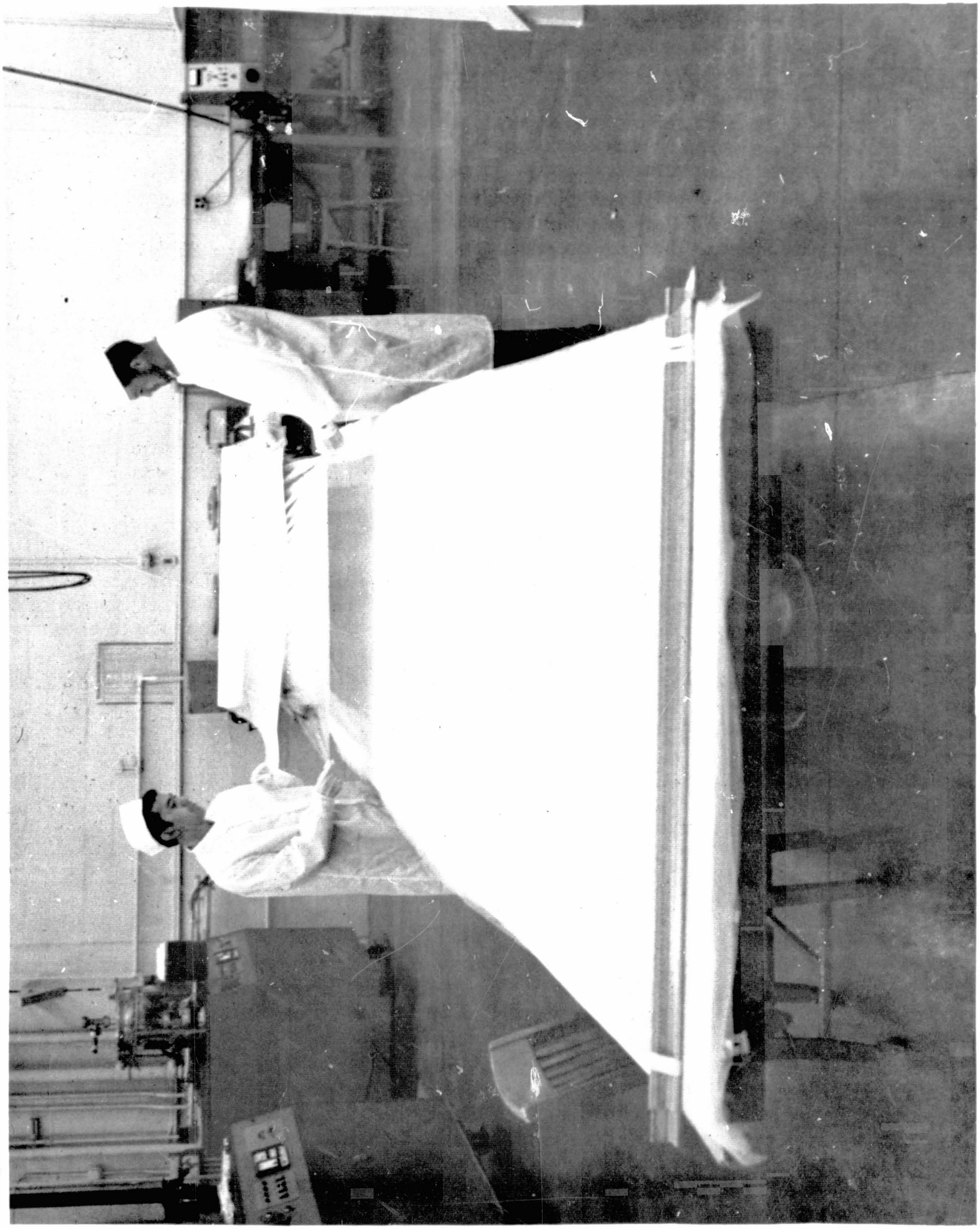


FIGURE 21
PANEL INSULATION LAYUP AND CUTTING METHOD

FIGURE 22

VIEW OF MULTILAYER INSULATION SYSTEM

FIGURE 23

CUTTING OF MULTILAYER INSULATION TO TEMPLATE

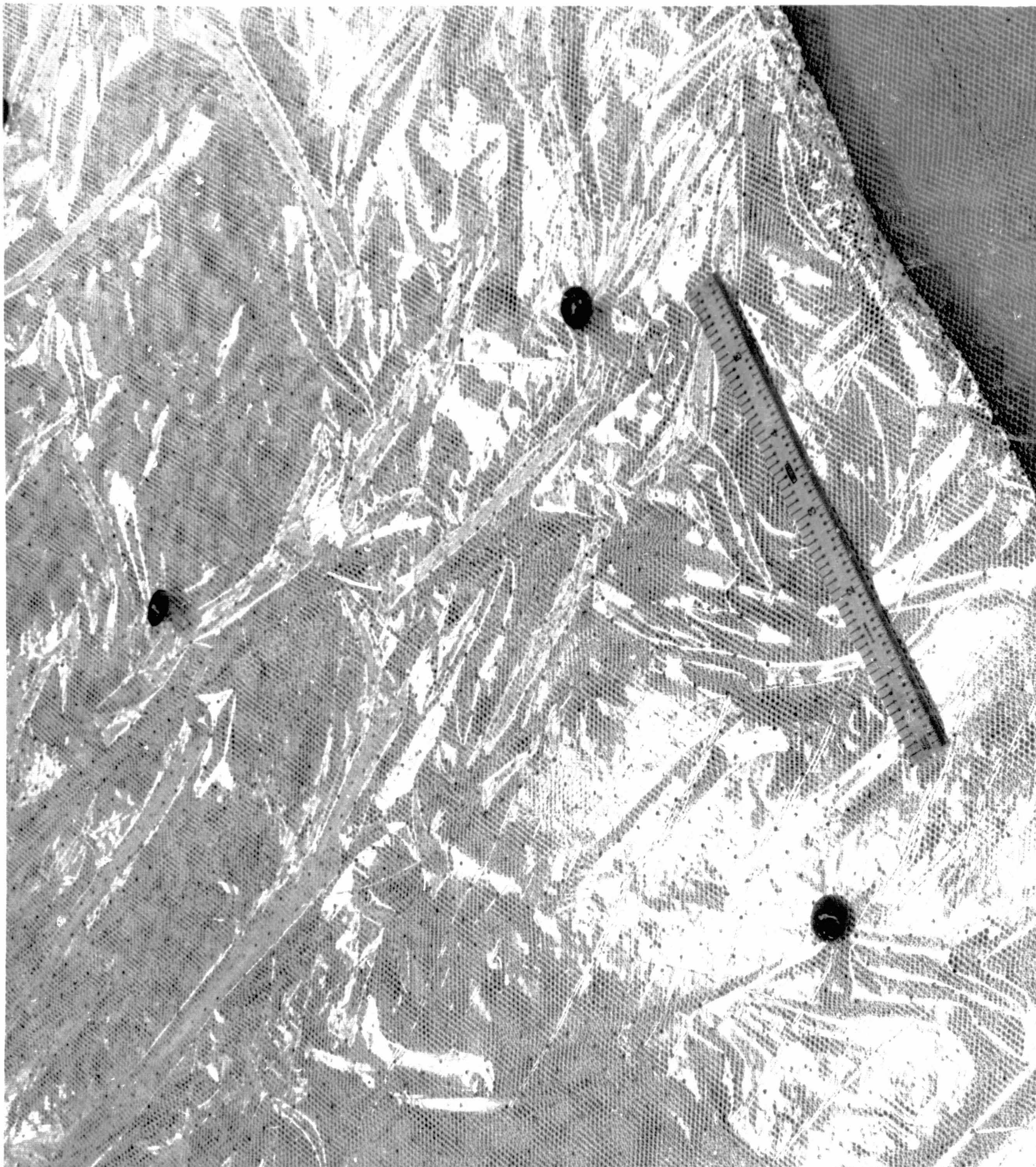


FIGURE 24

VIEW OF THREAD TIE ATTACHMENT INSULATION PANEL

3.5 Insulation System Installation

The insulation blankets were applied to the tank by first marking the position of the insulation support studs shown in Figure 25 followed by developing a hole at each location. The blanket was then installed over the studs and the retainers installed and bonded in place as shown in Figure 26. The thread retainers were inserted through the insulation blanket approximately perpendicular to the tank surface. The panels were then attached to the skirt by passing threaded loops over the support skirt clips and tensioning until snug. The opposite end of the blanket was sewn to the double-hoop assembly using nylon thread. The blanket butt edges were sewn to each other with nylon thread to prevent gaps in the insulation blanket. The completed segment is shown in Figure 27.

Fabrication of the insulation system posed no special problems which were not anticipated except that the insulation panel thicknesses were considerably less than anticipated. The thermal conductivity-layer density values in Figure 28 show that 55 ± 5 layers per inch is the optimum density for nylon tulle-aluminized mylar multilayer insulation. The Figure 28 also shows the effect of the increased layer density on the thermal conductivity in both the single blanket component and the composite assembly. The discrepancy in insulation thickness is due to perfect layering of the insulation during fabrication of the insulation blanket so that there was no wrinkling or overlapping of material. This density factor would not be a problem using Mylar honeycomb or rigid foam slices as there are fewer layers which are not compact sensitive. The completed system shown in Figure 29 also shows evidence of compaction in the sump area.

Additive to the blanket compaction during fabrication was the compaction of the blankets during application to the mock-up. This problem was prevalent in the sump fairing area between the support studs and in most of the upper half insulation area. The latter compaction is the result of the unit weight of the insulation compressing the underlying blankets. This compaction cannot be prevented when this type of insulation at this thickness is used. The prior compression problem is not as critical because the sump fairing only touches the sump at two incremental areas instead of the complete tank surface. This problem can be reduced by more careful placement of the holes for the stud support.

The thread retainers, as designed, were totally unsatisfactory. The threads could not be punctured through the insulation blankets exactly perpendicular to the attach button bonded to the tank which gave a devious path for the attachment thread. This allowed improper tensioning for each layer as only the fifth blanket was restrained and that only loosely because of the slack in the thread. Another problem was that the insulation blankets were sag-

ging by their own weight away from tank surface on the outside Y-ring area because the thread retainer did not hold them snug against the mock-up surface. This problem can be helped, but not completely rectified by the attachment of buttons to the threads as each layer is applied to the mock-up. An alternate solution is the inclusion of segmented stud supports similar to that shown in Figure 11F in the area of the Y-ring junction with the tank. These supports would increase the total insulation heat flow as shown in the summary chart on Figure 30.

The butt joints between the blankets tended to gap and sewing the joint at random locations did not completely close the gap because of the fragility of the net cover. The netting used for the insulation encapsulation tore easily and did not perform its function completely. It is recommended that the net used for encapsulating the blanket be a stronger nylon mesh material to allow stitching without tearing.

The scarfed ends of the insulation blanket had a tendency to sag within the encapsulating net in the area of the ends, especially after packaging and shipping. This can be rectified by sewing the first layer of the multiple scarf edge into the laminate of the nylon reinforcing tape and the nylon net layers. It is also recommended that the nylon reinforcing tape be placed on both the top and bottom of the end of the insulation blanket and sewn in place. This reinforcement is required to adequately support the insulation panels. This coupled with the stronger netting encapsulant should improve the fabrication and installation characteristics of the system.

The double-ring attachment assembly performed its function adequately.

The insulation restrainer threads inserted through the insulation in the Y-ring fairing area were impossible to install as planned. Personnel installing the insulation could not reach the height of the skirt which offered the only access. After reviewing the problem and experimenting with the relatively rigid insulation in the fairing area, it is recommended that the restraining threads be eliminated from the drawing.

FIGURE 25
POSITIONING OF SECOND PANEL LAYER FOR SEGMENTED SUPPORT LOCATION

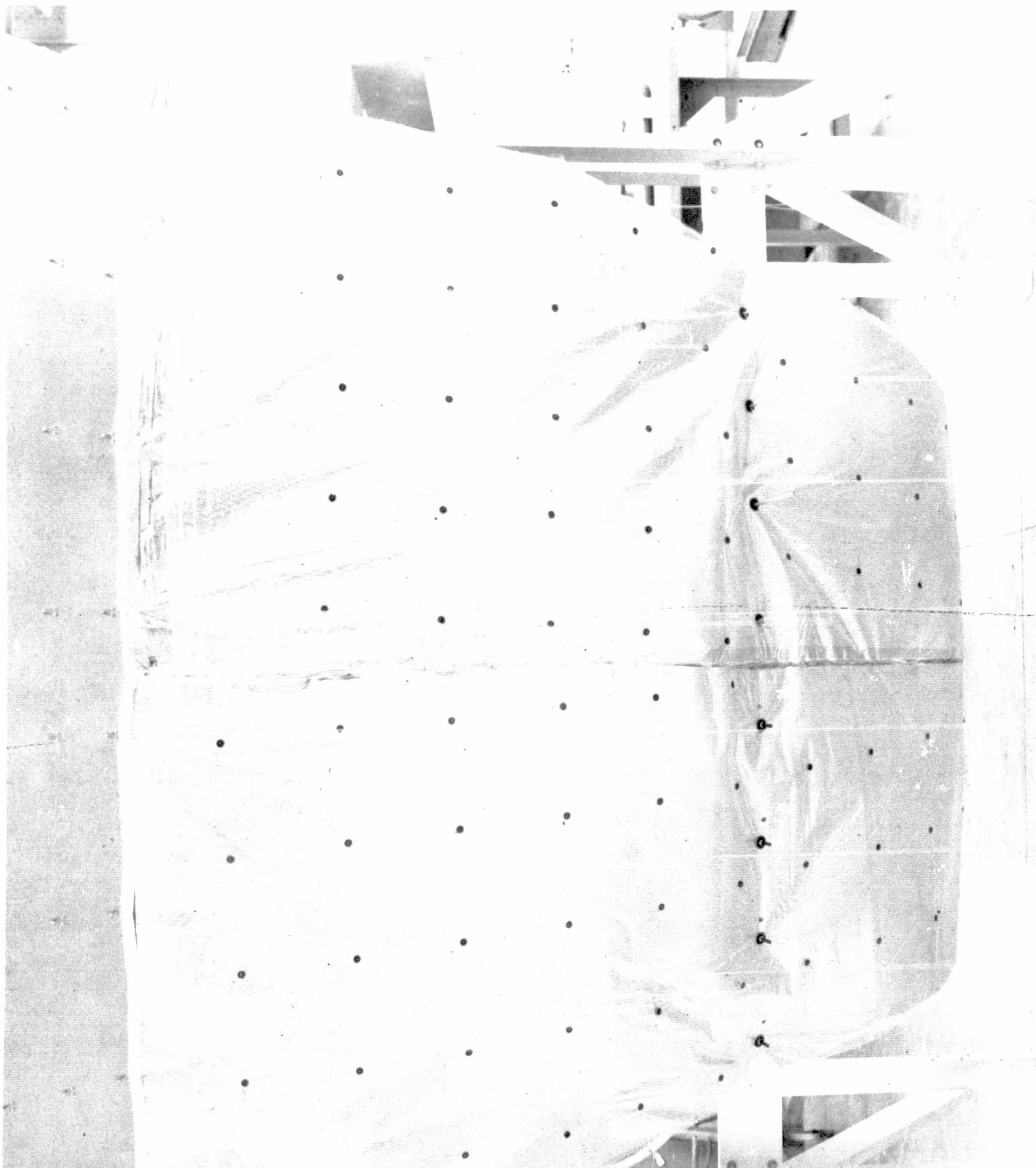


FIGURE 26

VIEW OF FIRST PANEL INSULATION LAYER INSTALLED

FIGURE 27

FIFTH PANEL LAYER OF INSULATION IN PROCESS OF INSTALLATION

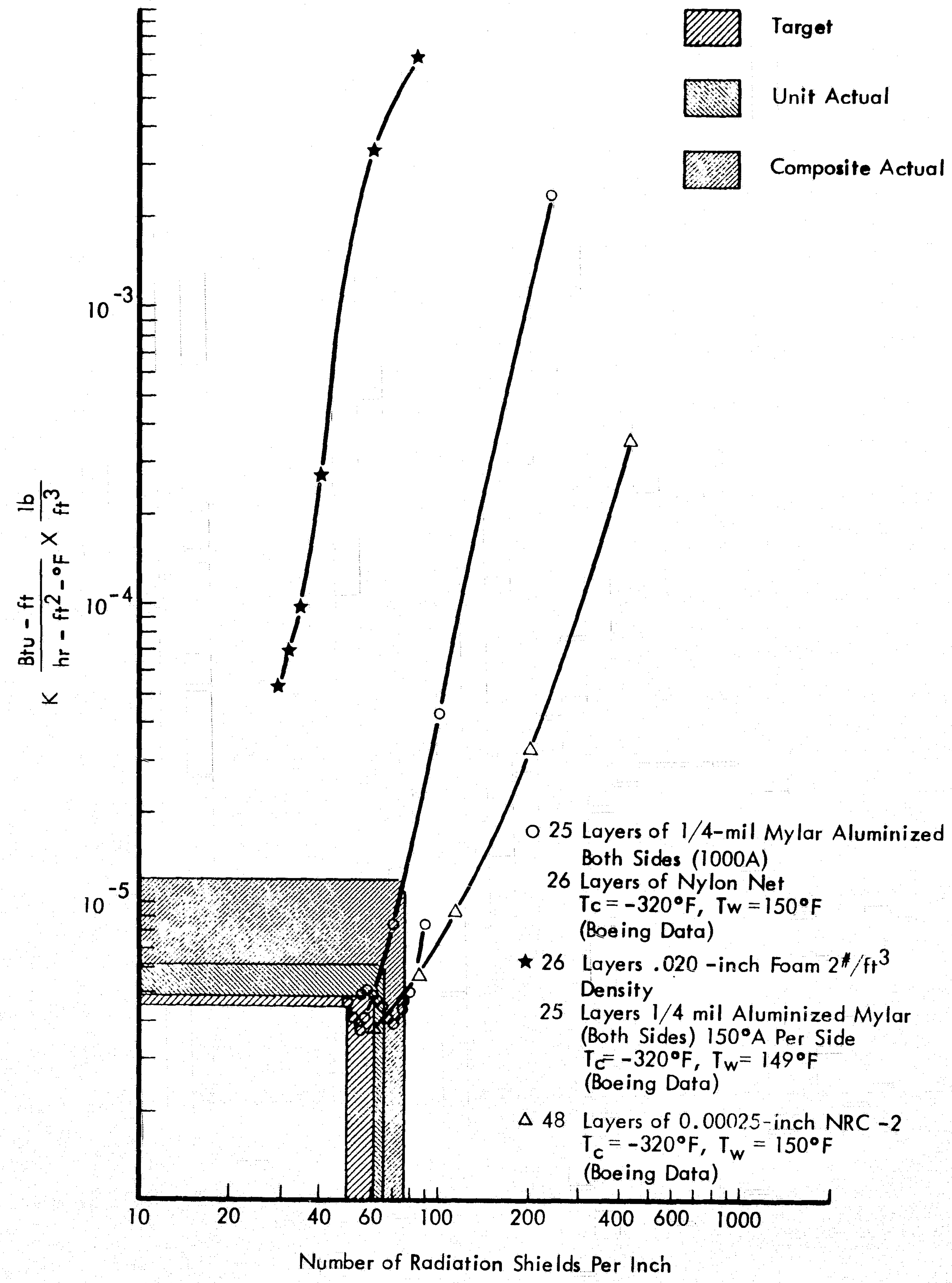


FIGURE 28

THERMAL CONDUCTIVITY/DENSITY PRODUCT FOR SOME MULTILAYER INSULATIONS

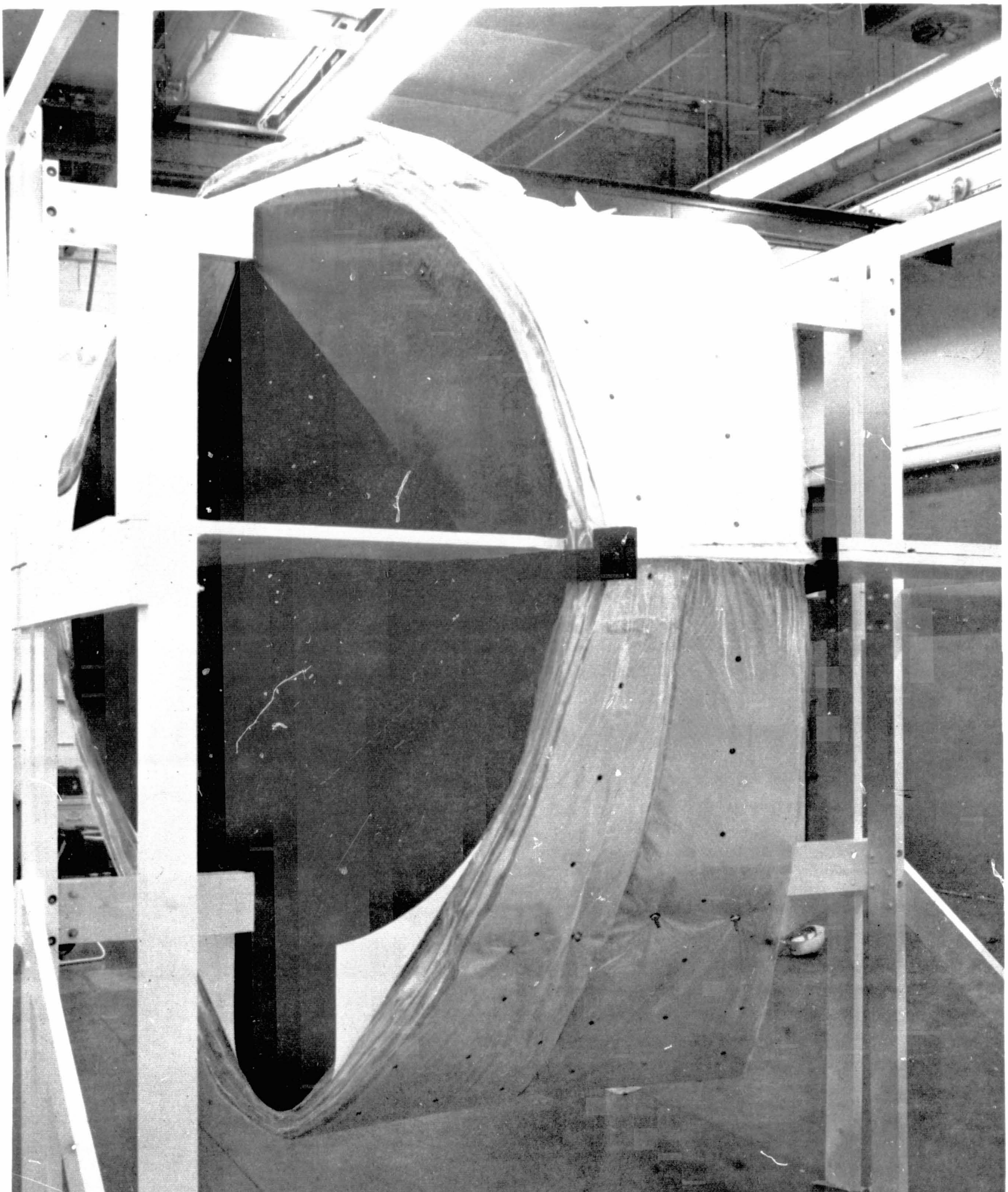


FIGURE 29
END VIEW OF INSULATION TO TANK CONFIGURATION

	Heat Flow (BTU/Hr) Predicted D2-109005-1	Predicted Modified System
Estimated Actual Performance in Zero "G" no Perforations	10.4	12.6*
Perforations in Radiation Shield	6.0	6.0
Studs	8.9	8.9
Support Web	0.2	0.2
Threat Ties	0.3	0.1
Segmented Studs	---	8.0
Tank Support	10.0	10.0
Manhole Insulation	5.0	5.0
Totals	40.8	50.8

*Change in value is due to compression of the insulation.

FIGURE 30

HEAT LEAK SUMMARY

3.6 Manhole Cover Insulation

The manhole cover areas were insulated per SK11-041071, sheet 3 of 5. Fiberglass wool insulation was inserted in the areas of the blanket layers shown in Figure 31 to give the appearance of that shown in Figure 32. A cap was fabricated and installed on the manhole cover and fastened with nylon thread shown in Figure 33. The outer cap was fabricated of multi-layer insulation. Velcro tape was installed in strips shown in Figure 33 instead of in a continuous band shown on the drawing as it was impossible to sew the tape in the manner specified on the drawing. The top cap covering the manhole was fabricated and installed over the cover areas as shown in Figure 34. This insulation cover was easily and readily attached and detached for access to the manhole cover.

The insulation retainer, previously discussed, was installed on the insulation system.

The completed mock-up unit is shown in Figure 29. This figure shows the conformity of the insulation system to the mock-up unit.

3.7 Disassembly, Shipping, Reassembly and Demonstration

The insulation system was removed from the mock-up unit, packaged in a polyethylene envelope dust cover and boxed for shipment. The mock-up unit was unbolted, split into two halves, braced, crated and shipped with the insulation system to the George C. Marshall Space Flight Center, Marshall Space Flight Center, Alabama.

The mock-up unit was reassembled by NASA-MSFC personnel. Boeing personnel provided technical assistance in the insulation reapplication and demonstration.

Two factors were evident in the demonstration phase in addition to those previously discussed. The insulation blankets when unpackaged for assembly had taken a noticeable compression set in the insulation materials giving rippled, wavy appearance. This set remained in the insulation blanket until the unit was applied and attached to the mock-up. The second problem was a noticeable but not serious gap of the butt joints of the insulation blankets. As shown in the photographs, Figure 26, 27 and 29 the gaps were not present in the insulation system initially but after packaging and shipping, sufficient shifting and creasing of the insulation occurred to make the gap sufficiently wide to be a problem. As true in all insulation installations, the inner insulation blankets (closest to the tank) were the most difficult to position and apply. This is due partially to the learning curve of the personnel involved and to the forgiveness of the underlying layers to that layer being applied over it.

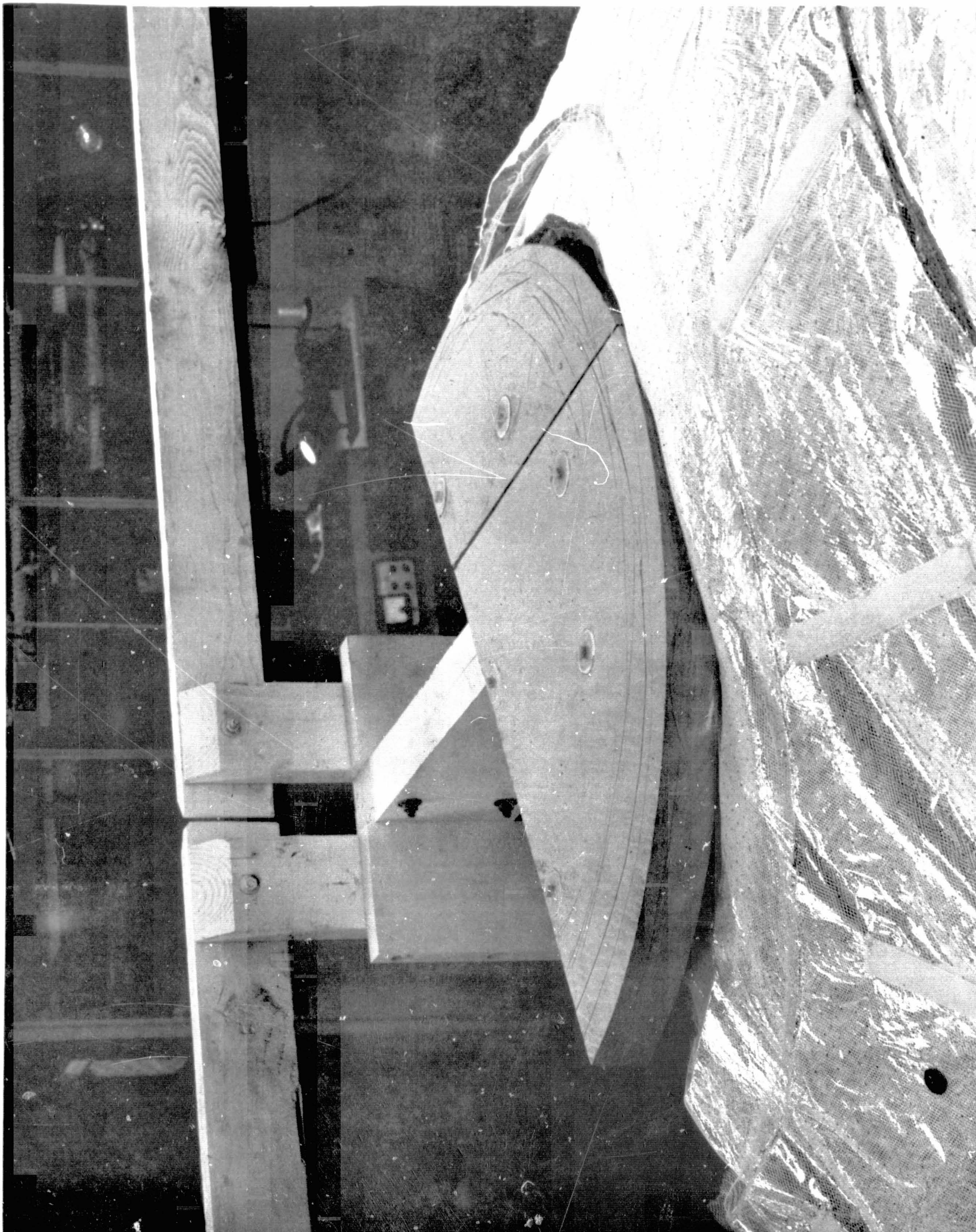


FIGURE 31
VIEW OF STEP INSULATION AROUND MANHOLE
PRIOR TO FIBERGLASS FILLER

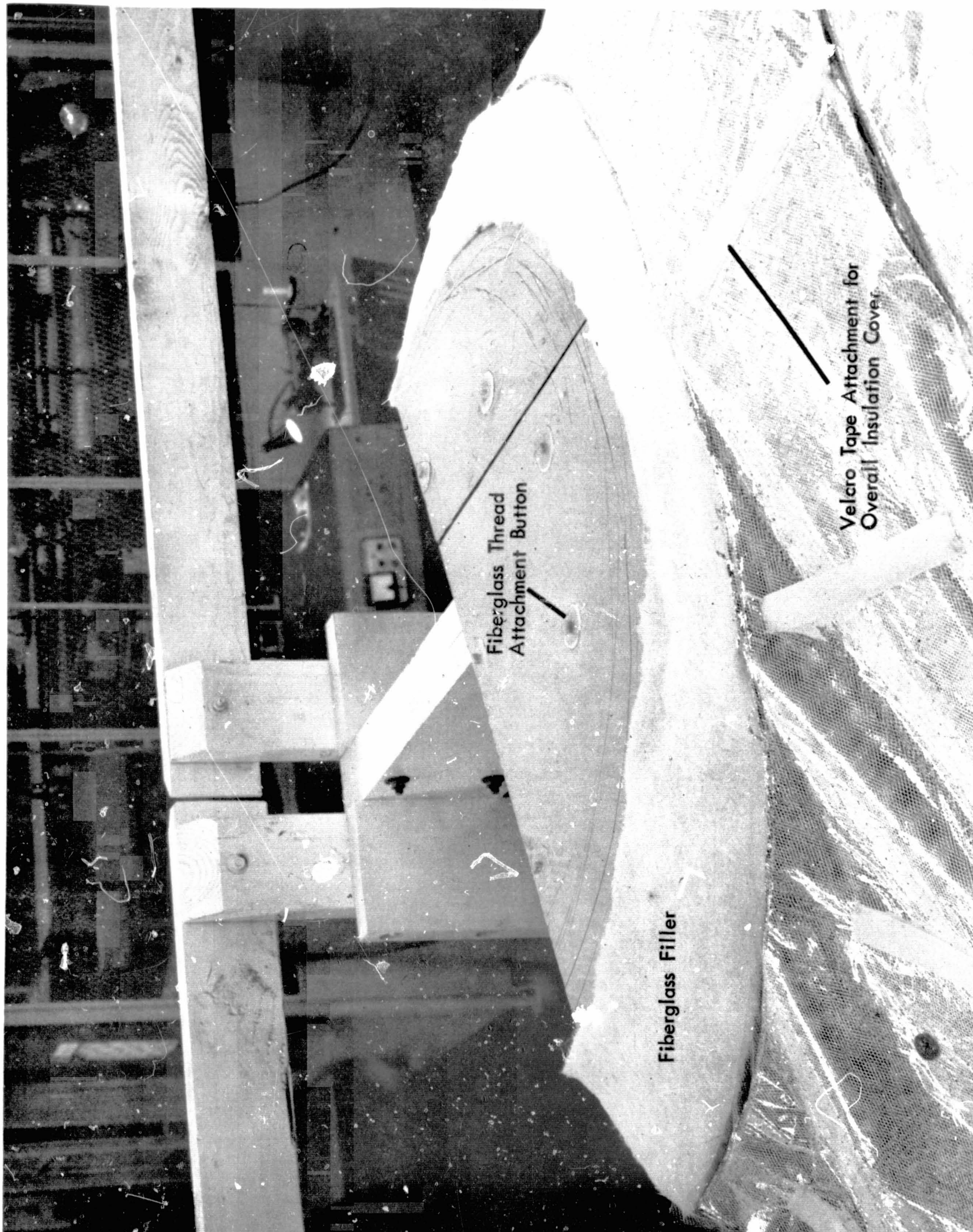


FIGURE 32
FIBERGLASS FILLER APPLIED BETWEEN STEP
INSULATION PANELS AND MANHOLE

FIGURE 33

MANHOLE INSULATION COVER

FIGURE 34

COMPLETED MANHOLE INSULATION COVERING

4.0 CONCLUSIONS AND RECOMMENDATIONS

The insulation system that was designed and planned for fabrication in NASA Contract NAS8-1172 was adequate to meet the program requirements as reported in D2-109005-1.

The demonstration of the mock-up pointed out several areas where difficulties were experienced in the insulation system and purge system.

4.1 Purge System

Difficulty was experienced in the distribution of gas to the purge section and the inability to control or determine the rate of purging from the system. The first problem became evident when the purge tubes crimped and completely shut off gas flow to the section. After an analysis of the problem a section of fiberglass cloth of coarse weave was rolled and inserted in each tube which prevented pinching and sealing of the transfer tube. An alternate to the glass cloth would be thin wall polyethylene tubing of small outside diameter which, when positioned within the transfer tubes, would prevent crimping and sealing of the tubes.

A redesign of the purge gas distribution system is desirable. The method specified in the drawing specified that the tubes exit the insulation system in the vicinity of the manhole insulation cover to be connected to an external manifold. It is recommended that metal distribution manifolds be fabricated and installed around the vent valves with arms radiating from this to the proximity of the manhole on each side. This system would offer an unlimited number of vents connections to the distribution tubes of the purge system compartments.

The purge system itself performed as anticipated after the purge gas distribution tubes restrictions were corrected. It was difficult to determine the flow characteristics and impossible to determine distribution quantities. It is recommended that an extensive study and developmental program be conducted to thoroughly explore this complexed problem area.

4.2 Insulation Attachments

The insulation attachment components presented the most areas for improvement in the complete system.

The skirt attachment clips should be inverted to the attachment position shown in the drawing to prevent cutting the thread attachments of the insulation blanket panels. This inversion will position the thread in the hook of the clip which provides a more stable attachment.

The segmented stud of fiberglass cones and washers did not perform as anticipated. The segments were difficult to position and hold in position while bonding, had poor dimensional control and had poor stiffness characteristics. A threaded bolt was required to maintain alignment. A segment stud of different configuration was designed and fabricated to replace the cone and washer support. This unit, shown in Figure 35, is easily fabricated, structurally sound, easily applied but has higher thermal conductivity. The advantages of this unit outweighs the conduction factor as these units are mounted on the sump fairing which itself is a poor thermal conductor being made of fiberglass.

The thread attachments should be redesigned to either provide a button tie on the thread each layer thickness or to eliminate the threads entirely and use segmented studs. It is felt that a thorough analysis of the problem would reveal that the studs would provide more adequate density control and support without sacrificing the entire efficiency of the system.

The insulation retainer fabricated of fiberglass preimpregnated material on a male mandrel did not have a channel wide enough to adequately rigidize it to the tank contour. It is recommended that the legs of the "U" shaped channel be extended to 1-inch long to accomplish this.

4.3 Insulation System

Theoretical and actual values for the insulation system are shown in Figure 36. A variety of difficulties were experienced in fabricating the insulation panels. Although they interrelate to other problems previously discussed, they will be treated separately below.

The insulation thickness of 55 ± 5 alternate layers of each perforated aluminized mylar and nylon tulle did not measure the required 1-inch thickness required for the ultimate conductivity factor. There is no known way of preventing this high density factor except to apply additional nylon tulle separator layers or to increase the thickness of the nylon tulle itself to compensate for the reduced thickness. It should be noted that this compaction would not occur with the sliced honeycomb (Mylar) spacers and would be less prevalent using foam spacers.

Additional compaction occurred in applying the insulation segment blankets to the upper half of the mock-up. This compaction occurred as the result of the weight of blanket layers compressing those underneath. Again, this would not be a problem with Mylar honeycomb or foam spacer materials which resist compaction because of structure and resilience. This compaction cannot be eliminated in the system selected as the weight of the upper layers compress those underneath.

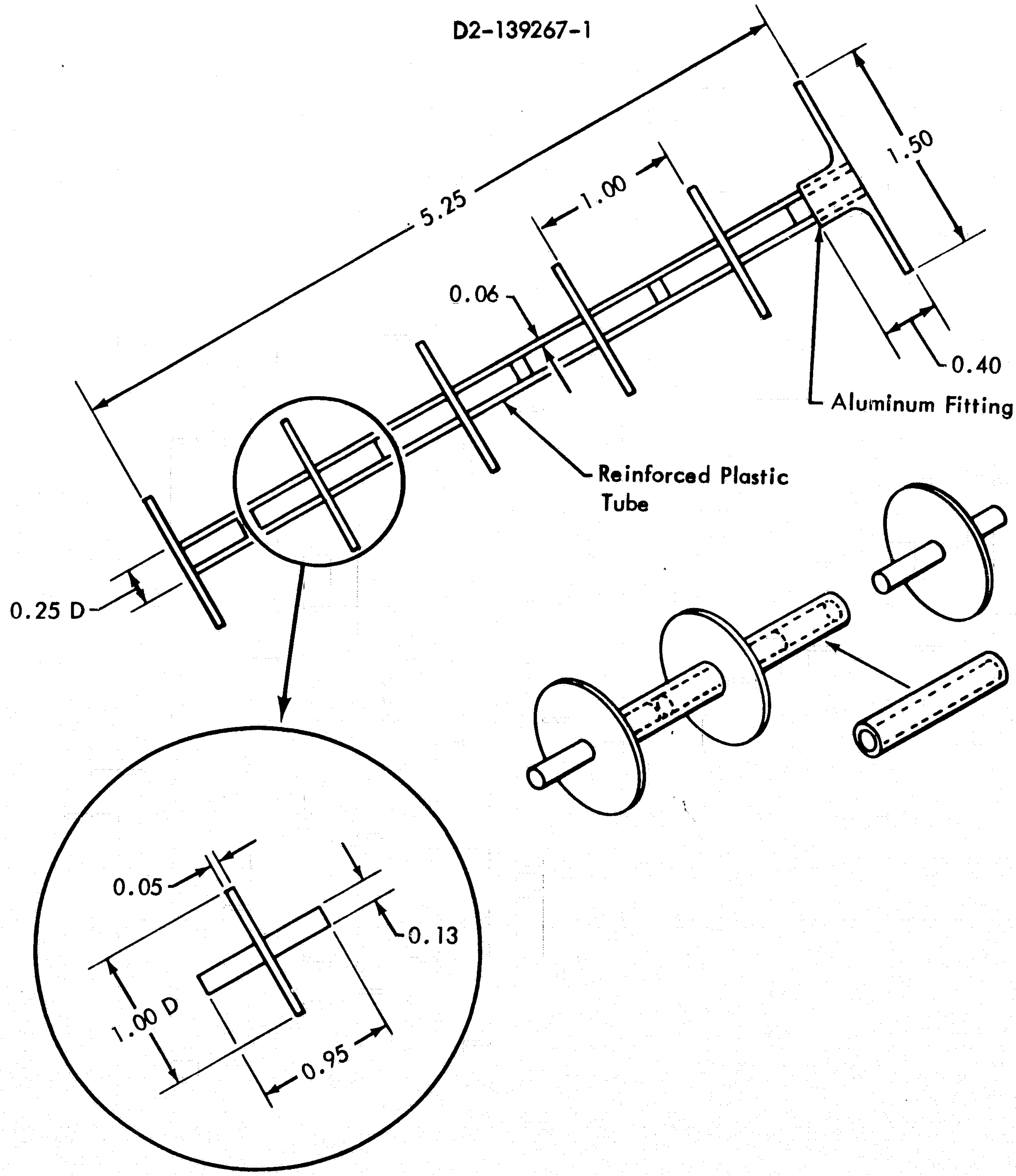


FIGURE 35
SEGMENTED INSULATION SUPPORT

	Number of Layers	Blanket Thickness (Inches)	Total Insulation Thickness (Inches)	Density (Lb/Ft^3)	$k = \frac{Btu - Hr}{Hr - Ft^2 - °R}$
Ideal	55 ±5	1.0	5.0	1.5	5.0×10^{-5}
Actual	55 ±5	0.80	Average 3.8	3.46	1.2×10^{-5}

FIGURE 36

PROGRAM SUMMARY

Compaction also occurred in the sump fairing area between the insulation support studs. This area is difficult to relieve but it is felt that through diligent care by the insulation installers, this compaction could have been minimized as the location holes in the insulation blanket control this tension.

An additional problem was the lack of support in the Y-ring area of the mock-up. In this area the insulation density was determined and maintained by the thread restrainers. As previously discussed, the threads did not function properly allowing the insulation to sag away from the mock-up. This insulation if allowed to hang would present flutter problems on the actual insulated article. A segmented stud previously discussed is recommended to replace the threads at the expense of higher thermal conductivity in this area. This is the only practical approach to insulation stability and density control.

4.4 Packaging and Shipping

The insulation materials must be stored and shipped in an unrestrained condition to prevent the compression and compression set which was evident in the mock-up materials.